Extreme Environment Electronic Packaging for Venus and Mars Landed Missions

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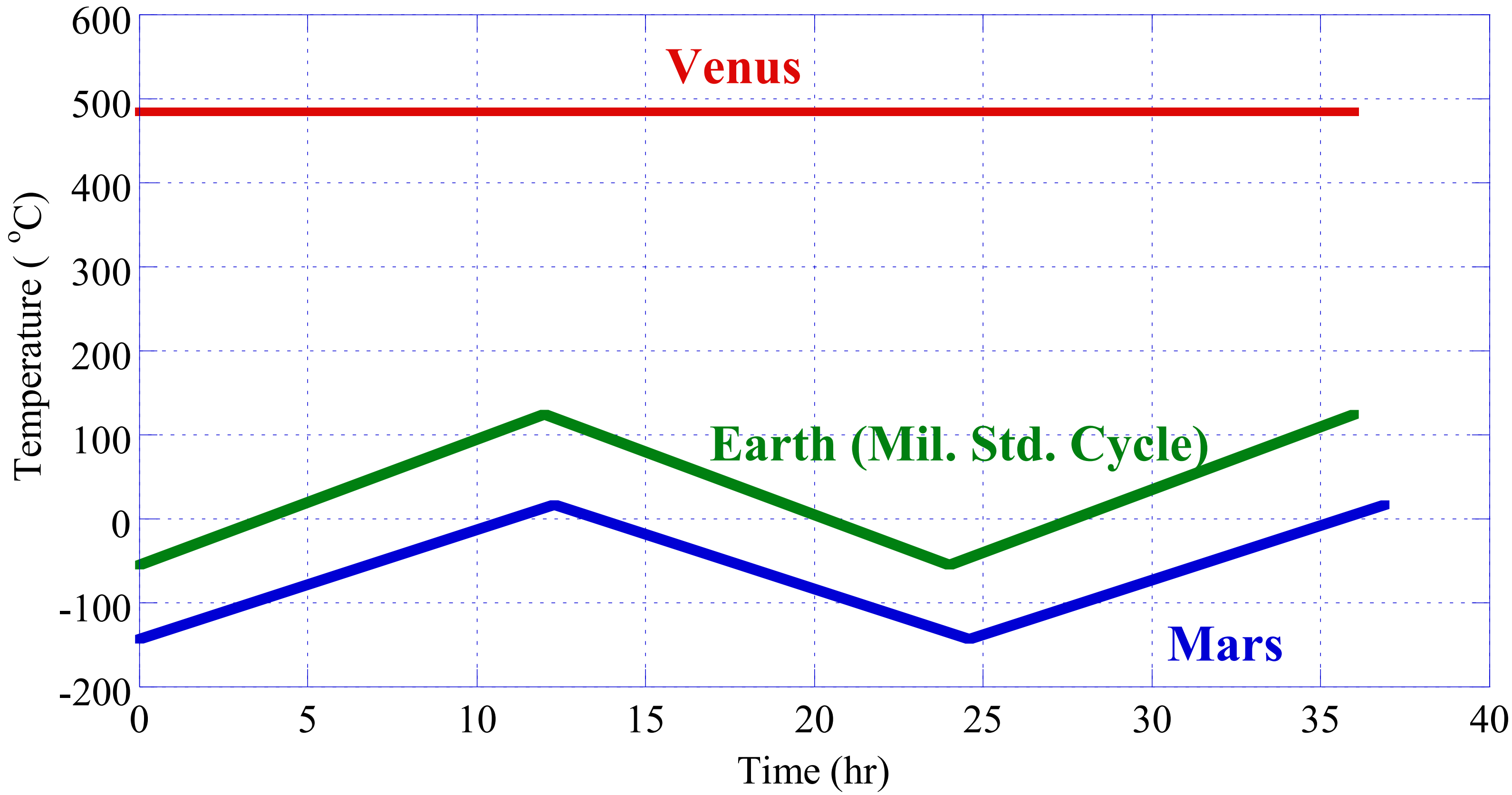
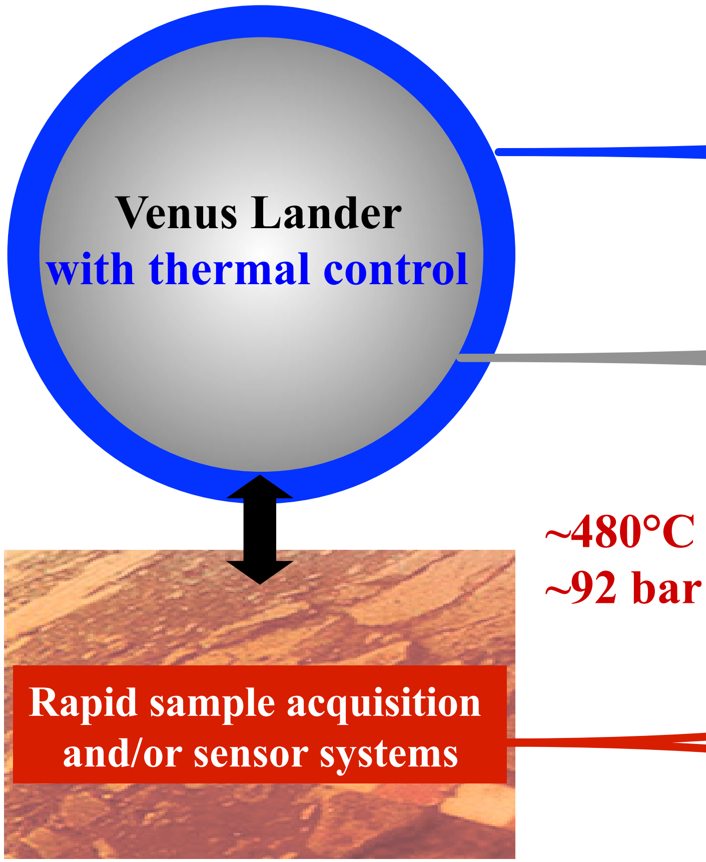
Target Space Environments



- Electronics and electronic packaging for space applications are generally qualified within the Mil. Std. temperature range of -55 to 125°C.
- The operation of electronic subsystems within the ambient environments of planets such as Venus and Mars requires the development and detailed evaluation of application specific electronic packaging configurations

Venus



Key High Temperature Components:

- Pressure vessel integrated with advanced thermal control
- High temperature electronics
  - Low power, operating at ~300°C
  - Some components (sensor and actuator interfaces and/or telecomm) at 480˚C
- Rapid data acquisition system
  - Rapid sample acquisition system at 480˚C
  - Rapid sample processing and analysis
- High temperature energy storage

Mars

Key Thermal Cycle Resistant Components:

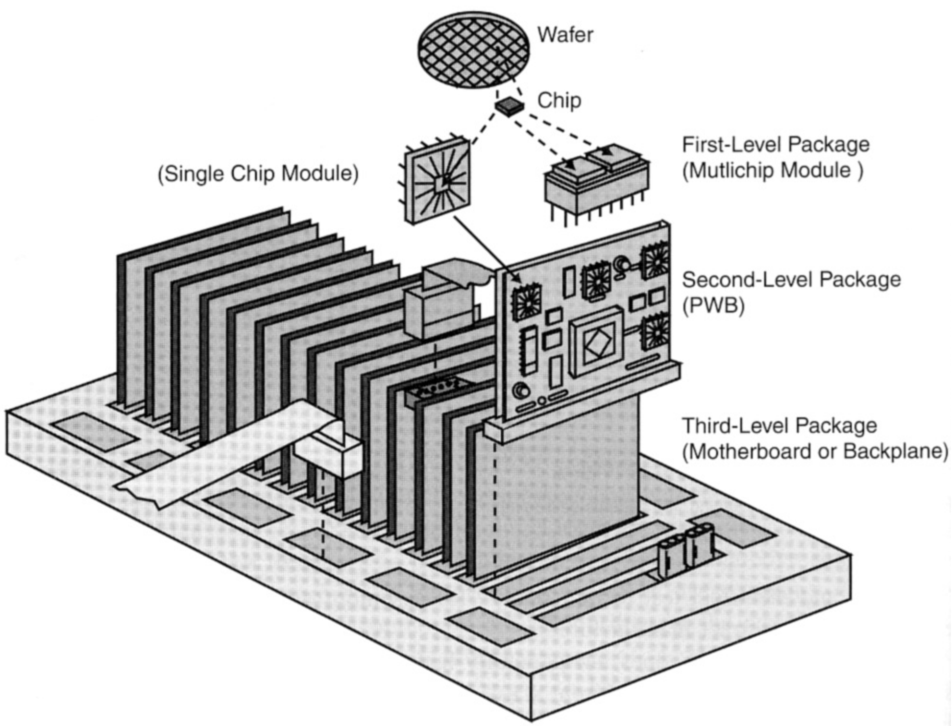
- Motor actuator drive electronics
- Electronics on extremities of system
- Instruments and sensors

Temperature Cycles: -120 to +20°C

Issues for Extreme Environment Electronic Systems

- System Requirements:
  - –Conditions under which electronics are expected to operate.
- Lifetime:
  - –Due to issues such as fatigue, diffusion, oxidation, and chemical reactions, assemblies will degrade with time and temperature.
  - –Such degradation must be understood and taken into account when designing future systems.
- Reliability
- Manufacturability
- Cost

What is Electronic Packaging?



"Fundamentals of Microsystems Packaging,"
Rao Tummala, McGraw-Hill, 2001

- Electronic Packaging includes all of the passive components and materials used to connect integrated circuits (or individual devices) and sensors to each other and with the outside world.
- This presentation will focus on the extreme environment challenges associated with First and Second Level Packaging.

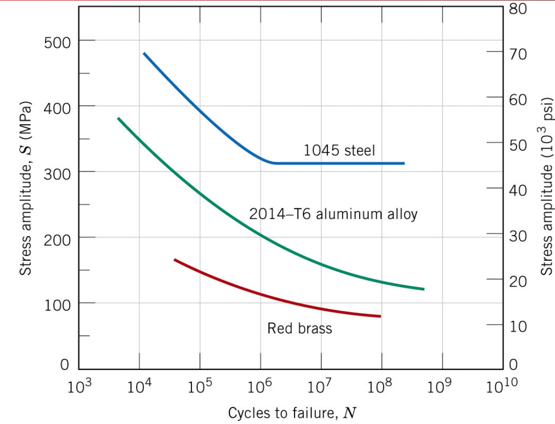
Failure Modes

- Microsystem Packaging Service Failure Modes for Extreme Environments
  - Over-Stress Mechanisms
    - Mechanical
      - Brittle fracture
      - Plastic deformation
      - Die cracking
    - Electrical
      - Radiation damage
      - Dielectric breakdown
      - Change in resistance
      - Change in capacitance
    - Chemical
      - Material degradation (e.g. melting, burning)
      - Other temperature dependent phase transformations
  - Time Dependent Mechanisms
    - Mechanical
      - Fatigue
      - Creep
      - Stress driven voiding
    - Electrical
      - Electromigration
      - Change in resistance
      - Change in capacitance
    - Chemical
      - Diffusion
      - Oxidation
      - Phase transformations leading to mechanical failure mode

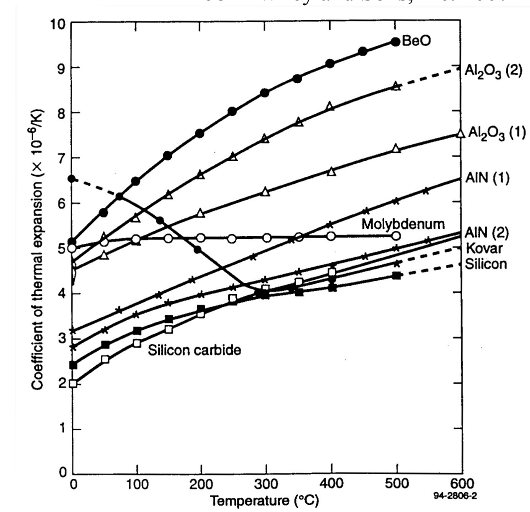
- High Temperature Electronics for Venus: material degradation, plastic deformation, creep, diffusion, oxidation, and electromigration are all of serious concern
- Electronics Resistant to Low Temperature Thermal Cycling on Mars: fatigue, which is influenced by phase transformations, embrittlement, and especially coefficient of thermal expansion differences, is the primary failure source

Fatigue - Mars

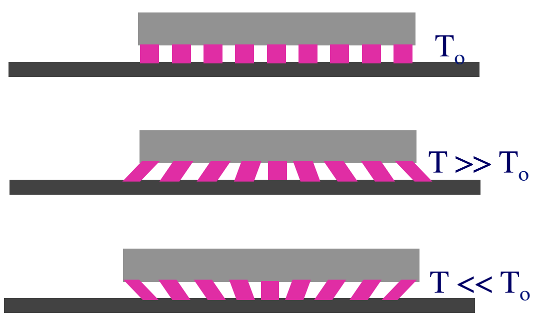
- Failure of electronic packages exposed to the low temperature thermal cycles of Mars is dominated by fatigue.
- Fatigue is the phenomenon of material failure under cyclic loading conditions.
- For electronic packaging, fatigue generally results from large temperature fluctuations and coefficient of thermal expansion (CTE) differences between adjoining materials.
- Examples of sites at which fatigue becomes a problem are solder joints, die attachment points, and wirebonds.

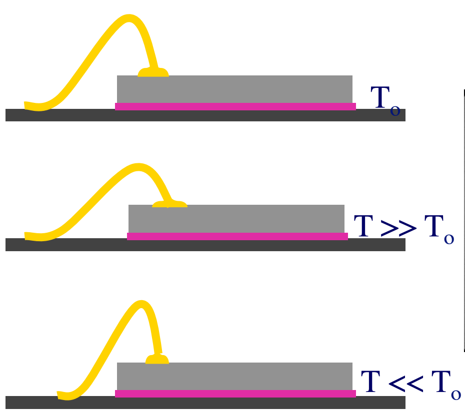


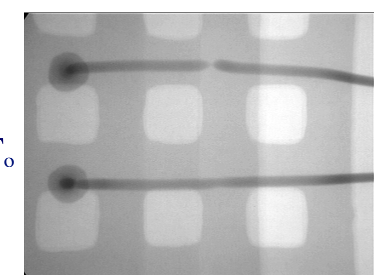
"Materials Science and Engineering: An Introduction, (7th Ed)", William D. Callister, Jr. John Wiley and Sons, Inc. 2007



"High Temperature Electronics," F.P. McCluskey, R. Grzybowski, T. Podlesak, eds., CRC Press, Boca Raton, 1997.

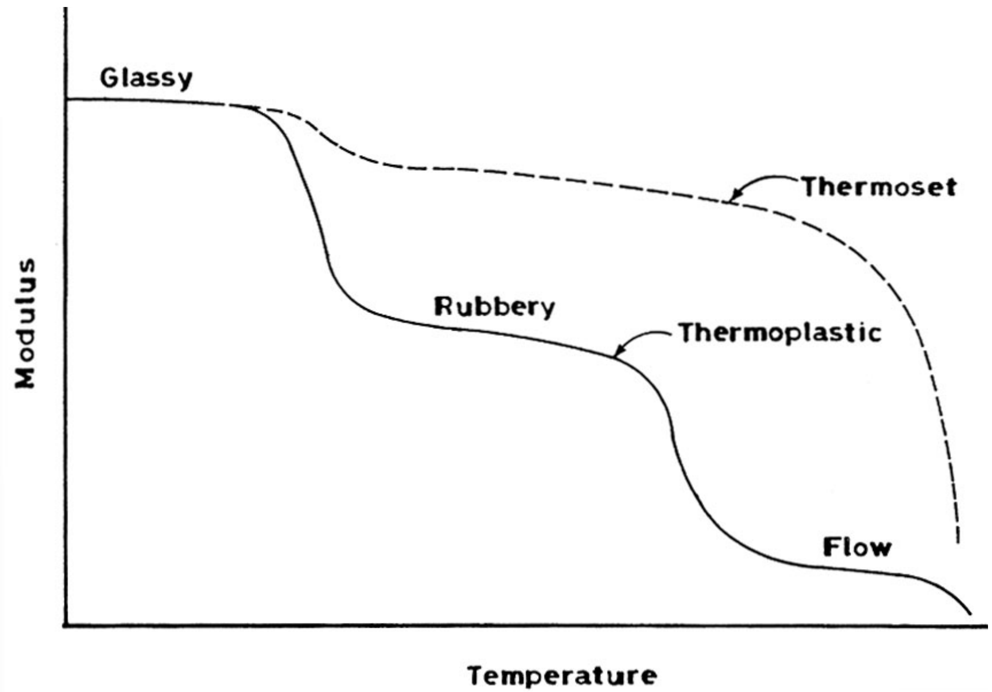






Low Temperature Phase Transformations - Mars

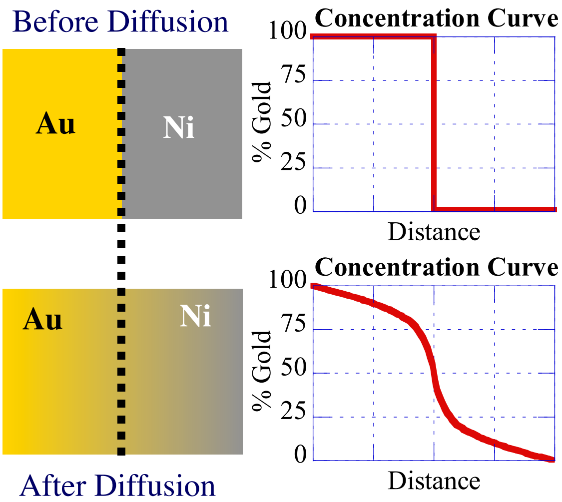
- Phase transformations that influence fatigue resistance, mechanical behavior and electrical behavior can also occur at the low temperatures of the Mars thermal cycle.

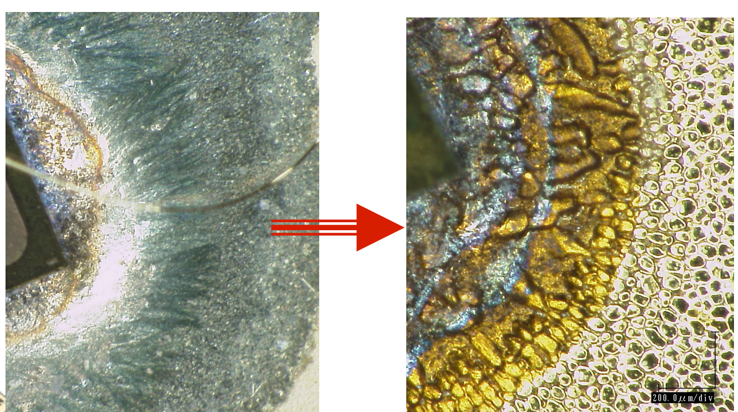


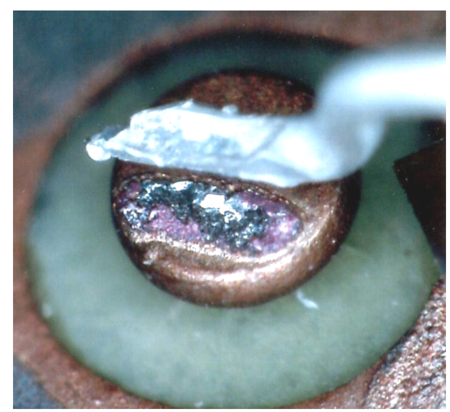
“Polymer Science and Technology,” Robert O. Edewele, CRC Press, 2000.

Diffusion and High Temperature Phase Transformations - Venus

- Solid state diffusion of dissimilar materials and oxidation of metals become significant concerns at elevated temperatures.
- Microstructural changes resulting from such interdiffusion can influence the strength, fatigue resistance, ductility and conductivity of the material.

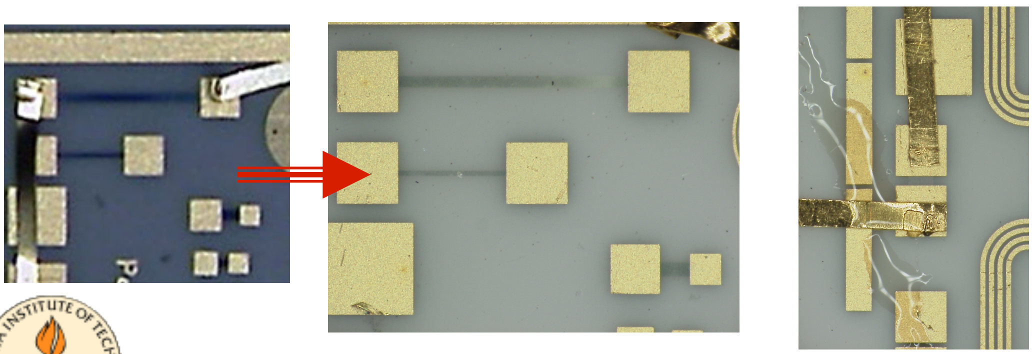






Degradation of Materials - Venus

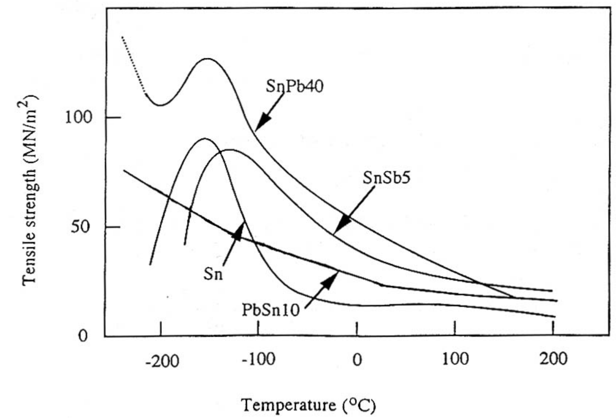
- The selection of materials for use in Venus electronic systems is dominated by materials degradation at elevated temperatures, including:
  - Melting of metals
  - Melting and burning of polymers
  - Softening of glasses



Die Attach Material	**Melting Temp (°C)**	**Limiting Properties/ Comments**
Solders		
Au80Sn20	280	Eutectic melting point
Au88Ge12	356	Eutectic melting point
Au97Si3	363	Eutectic melting point
Sn5Pb95	308	Solidus
Pb92In5Ag3	300	Solidus
Brazes		
82Au/18In	451	Solidus
45Ag/38Au/ 17Ge	525	Eutectic
72Ag/28Cu	780	Eutectic
82Au/18Ni	950	Eutectic
Other		
Au thick film paste	> 600	High firing temperature
Au thermo-compression bonding	➢500	Assumes Au to Au interface

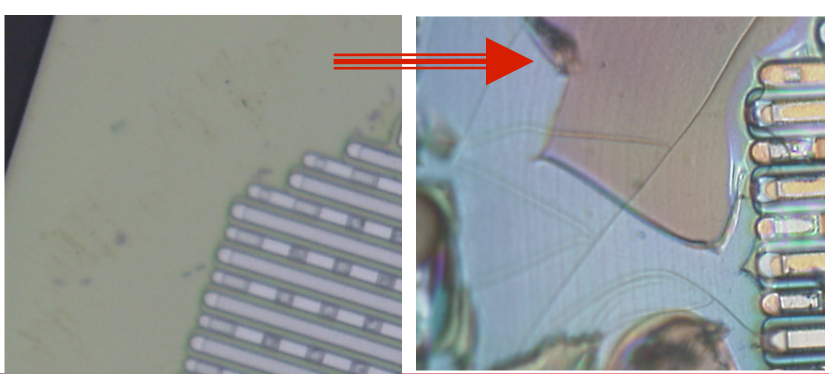
High Temperature Deformation - Venus

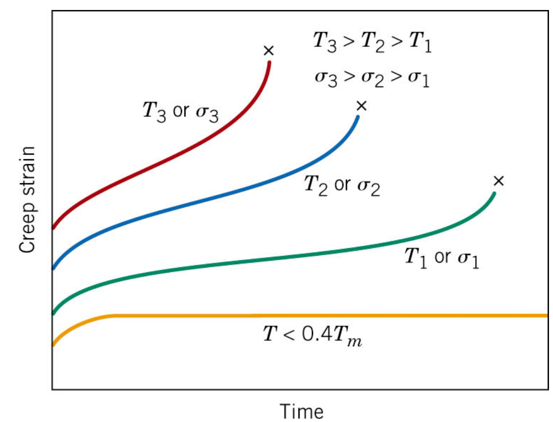
- Design for elevated-temperature service requires the consideration of the following:
  - Temperature dependence of static mechanical properties.
  - Time/temperature dependent plastic deformation under constant stress/load at elevated temperatures (creep).



"High Temperature Electronics," F.P. McCluskey, R. Grzybowski, T. Podlesak, eds., CRC Press, Boca Raton, 1997.

- Depending on the stiffness of the die attach material, CTE mismatch can lead to die cracking.
- Cracking of coatings can also occur due to CTE mismatch between the thin coating and the die.





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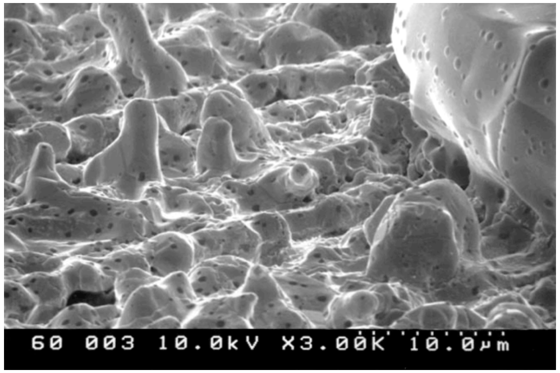
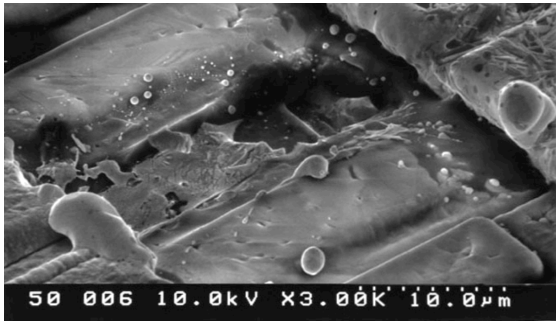
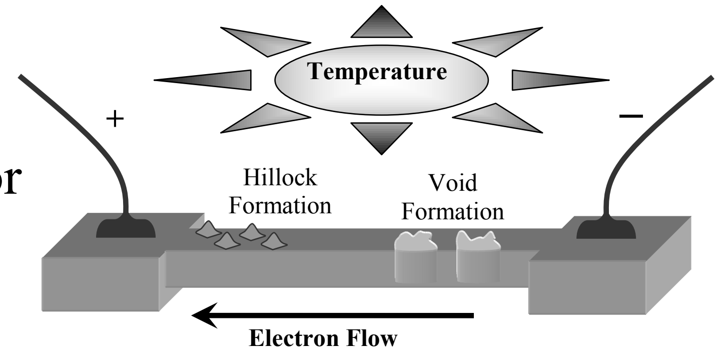
Electromigration - Venus

- Factors influencing electromigration include:
  - current density
  - temperature.
  - grain structure,
  - temperature gradients,
  - passivation coating selection (adhesion/degradation),
  - surface structure and migration,
  - stress distribution within the metal film,
  - distribution and selection of metal layers,
  - alloying effects,
  - surface roughness, and
  - CTE mismatch among the different layers.
- Due to the role of diffusion in electromigration and the fact that most active devices capable of working at elevated temperatures are power devices, electromigration becomes a considerable concern for high temperature electronic systems.



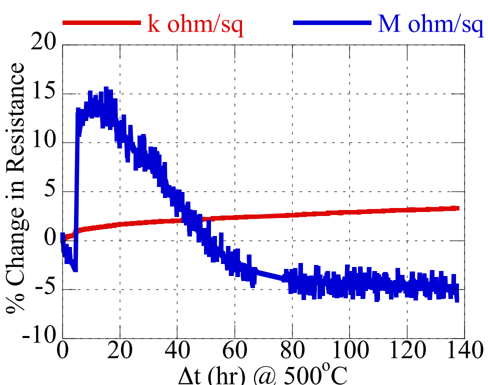


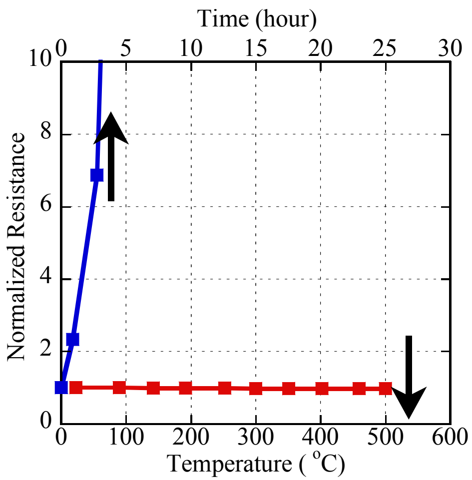


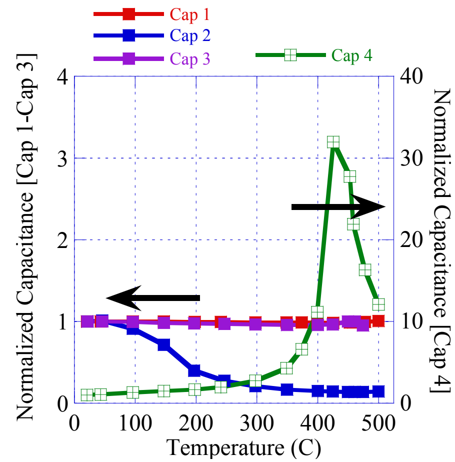
Passive Devices - Venus

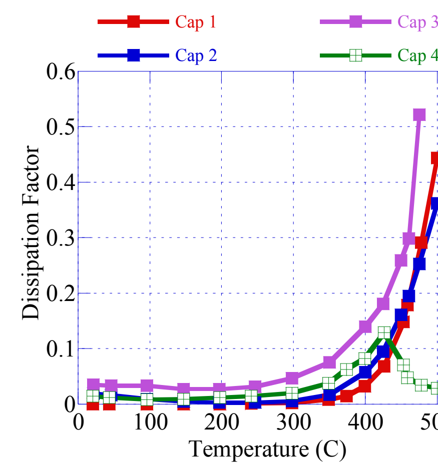
- Use of resistors at 500°C is complicated by drift, thermal stress, diffusion, and oxidation.
- Issues related to stress can be minimized by using thick or thin film resistors deposited on ceramic substrates.
  - Stability of thin film resistors at 500°C can be compromised due to instability of passivation layer.
  - Thick film resistors can exhibit drift at 500°C.

- Capacitors are particularly challenging components for reliable operation above about 300°C, since they exhibit variation with capacitance and dissipation factor.
- Experimental capacitors show great promise, but require further development.
- Unless resistor and capacitor have been designed for the target environment, they will fail due to problems with their enclosures and packaging much earlier than breakdown of the resistive material or dielectric.









JPL Extreme Environment Electronic Packaging Program Summary

- NASA and ESA needs for electronics and electronic packaging are unique, with environmental requirements that are well outside the temperature ranges required for most terrestrial applications.

- The development of electronics capable of operating directly within the ambient environment of the target planetary environments will allow the incorporation of distributed electronics into future missions.

- **Mars:** A program to evaluate the long term reliability of electronic packaging systems exposed to the extreme low temperature thermal cycles of the Mars environment is currently underway at JPL and has resulted in the development of design rules and materials selection guidelines for the Mars environment.

- **Venus:** Programs to evaluate electronic packaging systems and materials for the extreme high temperature environment of Venus are continuing at JPL. These projects are intended to yield models and design guidelines for future Venus Lander missions.